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Modeling the evacuation behavior considering the effect of dangerous source

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Abstract

Modeling the pedestrian's evacuation behaviour in danger is an interesting and challenging work. In this paper, pedestrian's microscopic psychological characteristics and movement characteristics of evacuation behaviour are discussed and analysed. A modified social force model is proposed to describe the movement behaviour affected by dangerous source. In this model, the concept of most possible detouring directions is proposed, and an algorithm of calculating the directions is introduced. The self-driven force and repulsive force are reformulated. The spreading dynamics of dangerous source and coefficient of risk are integrated into this model. Simulations in a room with a single exit have been implemented. According to simulations, the influence of the factors, such as exit width, risk coefficient, scale of crowd is discussed in detail. The simulation results show that our model can reproduce the 'fast-is-slow' effect in dangerous situation. A large risk coefficient may reduce the evacuation time in some extent.

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Keywords: evacuation behaivor; dangerous source; flow characteristics; social force model

1. Introduction

Large scale public places are very important in our daily lives. In recent years, security incidents occur constantly in these places. Fire, poison gas, power failure, or other hazards may threaten personal safety and disrupt individual

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behavior during evacuation. Scientific management and effective design are urgently needed to guarantee crowd in a normal and safety status. Understanding the characteristics of pedestrian dynamics during evacuation process in emergency is the key issues in crowd management (Fruin, 1971, Wood, 1972). In dangerous situation, pedestrians may be crowded, nervous or even panic. If pedestrians make some irrational behaviors, it may lead to fatalities or injuries of crowd. It is necessary to deeply discuss and model the evacuation behavior affected by dangerous source.

There are many models that describe the pedestrian's individual movement behavior (Hoogendoorn & Bovy, 2005). These models mainly consist of spatial-discrete models and spatial-continuous models. Cellular automation (CA) model (i.e., Okazaki & Matsushita, 1993, Blue & Adler, 1997, Kretz, 2007, Varas et al., 2007; Bandini et al, 2014; Leng et al, 2014) and lattice gas (LG) model (i.e., Hoogendoorn & Bovy, 2000) are widely used spatial-discrete models. In these models, the research area is divided into a series of homogeneous cells, and each pedestrian occupies one or several cells. Based on given movement rules, pedestrian can move to one of the neighbor unused cells by transition probability. The concept of floor field (FF), including static floor field and dynamic floor field, has been proposed to describe the movement (Schadschneider, 2001; Huang & Guo, 2008; Fu et al., 2013; González et al., 2013).

Compared with spatial-discrete model, pedestrian can discretionary move in a two-dimensional planar in spatial-continuous models. In the models, social force model is a well-known model, which precisely describes pedestrian movement (Helbing et al, 1995, 2000, 2002; Parisi & Dorso, 2005; Antonini et al, 2006; Seyfried et al., 2006; Johansson et al., 2008; Suzuno et al, 2013; Zeng et al., 2014). This model is based on the Newtonian's second law of motion, and pedestrian movement is driven by external forces, including self-driven force, non-contact social force, and contact force. It has been successfully applied to quantitatively reproduce the fundamental diagram in corridors, evaluate the flow characteristics through bottlenecks, and investigate self-organized phenomenon in evacuation process. Many researchers have improved the model to simulate pedestrian movement in different situations, such as normal condition, crowed condition, and panic situation (Moussaid et al. 2011, Kwak et al, 2013). In addition, route choice behavior has been included into the model to describe the pedestrian evacuation process in large scale places with many exits (Wagoum et al, 2012, Werberich et al., 2014). However, these models do not mention the hazard situation, and not consider the effect of the dangerous source.

In hazard situation, the dangerous source may impact pedestrian's behavior. For example, in fire, pedestrians always keep away from the fire to prevent themselves from being burnt (Guo et al., 2013). When pedestrians get closer to the fire source, they may get nervous and accelerate their desired velocities to leave from it as soon as possible. Pedestrians will make a tradeoff between minimization of walking time and persistence of personal safety. Nearby dangerous source, radical people may prefer to rush through it in a short time, while conservative people may prefer to make a detour from it in a safe status. In addition, pedestrian's behavior will also be influenced by the spreading features of dangerous source, such as fire smoke, poison gas. People may dynamically adjust their movements to adapt to the surrounding environment.

In this paper, an improved social force model is proposed to describe the movement behavior of evacuation process in dangerous situations. First of all, the features of pedestrian movement behavior are discussed in Section 2. Considering the influence of dangerous source on movement behavior and choice behavior, the modified formulations in social force model are introduced in Section 3. Simulations are implemented to investigate the evacuation dynamics and evaluate the egress time in Section 4. Section 5 is the conclusion.

2. Characteristics of movement behavior in dangerous situation

When walking in a street or evacuating from a room, a pedestrian will be influenced by other surrounding pedestrians and obstacles. If there are some dangerous sources, pedestrian's movement behavior will be also influenced by the dangerous sources. In face of danger, pedestrian may reflect some negative psychological activities (i.e., intension, fear, panic) or positive activities (i.e., unity, enthusiasm, humility). These activities may have a significant impact on the cognition and decision behavior. If pedestrians are in negative condition, they may not make their decisions by themselves, and congestion phenomenon and conformity behavior may occur.

The features of pedestrian behavior in danger are mainly embodied as: (1) pedestrian wants to leave dangerous area quickly with a higher desired velocity; (2) pedestrian behavior is with larger fluctuations; (3) pedestrian experiences a repulsive force from dangerous source; (4) pedestrian prefers to make a detour from dangerous source with a shortest distance; (5) arching-queue may form near the exits; (6) conformity phenomenon appears when pedestrian does not know how to make an optimal decision.

Pedestrian evacuation behavior in danger is affected by many factors, such as structure layout, information of dangerous source, individual capabilities, and social relationship. During an evacuation in danger, pedestrian may try to prevent them from being hurt. The unwilling to get close to dangerous source can be describe a repulsive force, which is related to the distance between pedestrian and dangerous source, the extent of damage of dangerous source, and the response specialty of pedestrian. Pedestrian wants to move fast to leave danger regions, and the dangerous source affects pedestrian's desired velocity. When pedestrian recognizes the dangerous source, he/she will choose an optimal direction to walk along. Assume that the region of dangerous source is a circle, the tangential direction of the circle will be the shortest walking distance without collision with dangerous source. Pedestrians will raise their desired velocities to quickly walk through dangerous source or reduce exposure to dangerous source. Pedestrian's behavior in emergence is influenced by the dynamic spreading features of dangerous source, which depend on composition of hazards, construction materials, and air conditions. For example, in fire, pedestrians will adjust their decisions and velocities to keep away from the fire and smoke.

The decision-making behavior in emergence situation is crucial in evacuations, which is quite different from the behavior in normal condition. Firstly, the decision made in emergence is sometimes a life-or-death decision. If the pedestrian had chosen a congested path or exit, he/she would spend a lot of time on congestion or queuing, and would get hurt by dangerous source. Secondly, the decision is made in a short time. When some danger occurs, a pedestrian may have very limited time to make a response to it. Consequently, the emergent reaction will cause psychological pressure. Pedestrians under tremendous pressure may be nervous, panic, reduce their recognition abilities, or even make irrational choice. Thirdly, the cognitive information of a pedestrian is indistinct, incomplete or sometimes scarce. Pedestrians with little information may follow others to make their decisions, and then conformity phenomenon may occur.

3. Modified social force model

Social force model is a well-known force-based model that precisely describes the pedestrian movement behavior and quantitatively reproduces self-organized phenomena. In the model, each pedestrian i is regarded as a circle, an ellipse or a three-circle, and the pedestrian's movement is driven by internal and external forces, which include self-driven force $\mathbf{f}_i^s$, non-contact force $\mathbf{f}_i^n$ and contact force $\mathbf{f}_i^c$, in Eq. (1) .

$$\mathbf{f}_i = m_i d\mathbf{v}_i / dt = \mathbf{f}_i^s + \mathbf{f}_i^n + \mathbf{f}_i^c \tag{1}$$

Researches have made a lot of modifications on the model to investigate movement in normal conditions (Parisi et al., 2009); however, few of them concentrate the movement in danger situation. In this section, the influence of dangerous source on pedestrian movement is mathematically formulated, and a modified social force model is proposed to describe the movement in face of danger source. In our model, the modifications are concentrated on the calculations of self-driven force and contact force from dangerous source.

3.1. Self-driven force

Self-driven force reflects that pedestrian is willing to move at a desired velocity. If current velocity $\mathbf{v}_i(t)$ deviates from the desired velocity $\mathbf{v}_i^0(t)$, the pedestrian will make an adjustment by exerting a self-driven force. Self-driven force is usually formulated by Eq. (2).

$$\mathbf{f}_i^S = m_i \left[v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t) \right] / \tau_i \tag{2}$$

Here, m_i represents the mass of pedestrian, $v_i^0(t)$ is the magnitude of desired velocity, $\mathbf{e}_i^0(t)$ is the direction of desired velocity, and τ_i is a relaxation time. The relaxation time is defined that a pedestrian tends to correspondingly adapt his/her actual velocity to desired velocity with a certain characteristic time (i.e., Helbing et al., 2000; Moussaid et al., 2011).

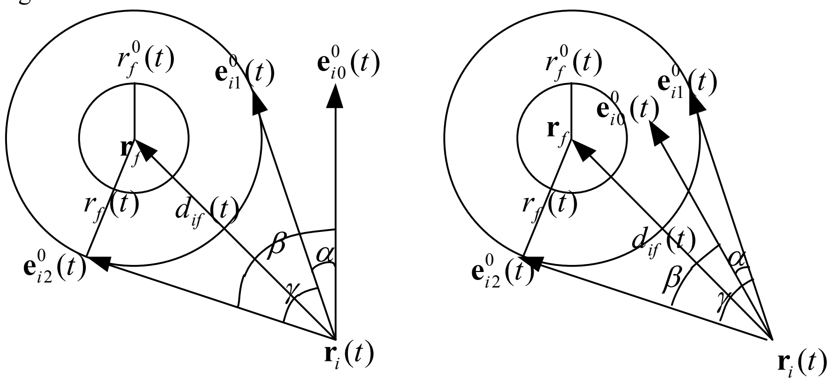
Under the influence of dangerous source, pedestrian is always nervous or panic, and is willing to move through the dangerous source as fast as possible. When getting closer to dangerous source, pedestrian will speed up and make a detour. Therefore, the desired velocity is higher than that in normal condition, and the magnitude of the velocity depends on the extent of panic, which is formulated as Eq. (3). The velocity is assumed to be the linear combination of the current velocity and maximal velocity.

$$v_i^0(t) = [1 - p_i(t)]v_i^0(t) + p_i(t)v_i^{\max} \tag{3}$$

Here, $p_i(t)$ is 'panic coefficient', $v_i^0(t)$ is the current desired velocity, and $v_i^{\max}$ is the maximal velocity. If pedestrian is panic with a large coefficient, the desired velocity tends to the maximal velocity; otherwise, the desired velocity tends to keep changeless. Different from Helbing et al. (2000), $p_i(t)$ is assumed to be influenced by the distance between dangerous source and pedestrian location. The shape or influence region of dangerous source is various, and enumerating all the geometries is almost impossible. The closet distance between two shapes can be easily calculated by adopting the circle shape, so the influence region of dangerous source is assumed to be a circle in this paper. The $p_i(t)$ is then defined as Eq. (4). $r_{f\max}$ is the maximum distance, and $r_{f\max} = 3 \cdot r_f(t)$. r_f^0 is the 'hard region' that pedestrian could not move into.

$$p_i(t) = \max\left\{\left(r_{f\max} - d_{if}(t)\right)/\left(r_{f\max} - r_f^0 - r_i\right), 0\right\} \tag{4}$$

When pedestrian gets close to dangerous source, he/she will make a detour from it. In the range of dangerous source, two instances of the relative location between pedestrian and dangerous source are illustrated in Fig. 2 and Fig. 3. Here, $\mathbf{r}_f$ is the center of dangerous source, $r_f(t)$ is the dynamic radius of dangerous source, $\mathbf{r}_i(t)$ is the location of pedestrian i, $d_{if}(t)$ is the distance between the center of pedestrian and the center of dangerous source. Then, $d_{if}(t) = \left\|\mathbf{r}_f - \mathbf{r}_i(t)\right\|$. In addition, $\mathbf{e}_{if}(t)$ is the direction of pedestrian location pointing to dangerous source, and $\mathbf{e}_{if}(t) = \left[e_{if}^1(t), e_{if}^2(t)\right] = [\mathbf{r}_f - \mathbf{r}_i(t)]/d_{if}(t)$. $\mathbf{e}_{i0}^0(t) = [e_{i0}^1(t), e_{i0}^2(t)]$ is the velocity direction without the influenced by dangerous source, while $\mathbf{e}_{i1}^0(t), \mathbf{e}_{i2}^0(t)$ are the tangential directions to dangerous source which are the most possible detouring directions.



a) Inside the region of the included angle b) Outside the region of the included angle

Fig. 1 Illustration of the pedestrian outside the dangerous source

Fig. 1 illustrates the situations that pedestrian is outside the region of dangerous source $\left(d_{if}(t) > r_f(t)\right)$. Here, α, β represents the included angle between $\mathbf{e}_{i0}^0(t)$ and $\mathbf{e}_{i1}^0(t), \mathbf{e}_{i2}^0(t)$ respectively. In Fig. 1(a), if dangerous source does not block pedestrian's vision field $(\alpha+\beta>\gamma)$, the pedestrian will not be influenced by the dangerous source, and will choose the current direction of desired velocity $\mathbf{e}_{i0}^0(t)$. In Fig. 1(b), if dangerous source blocks pedestrian's vision field $(\alpha+\beta=\gamma)$, the pedestrian will make a complete detour from it according to the two possible directions $\mathbf{e}_{i1}^0(t),\mathbf{e}_{i2}^0(t)$. By comparing the two included angles α,β, pedestrian will choose a direction with smaller detouring angle $\mathbf{e}^*$. It is because pedestrian prefers to make changes of direction as small as possible. The calculations of the two tangential directions and relevant included angles are listed as follows:

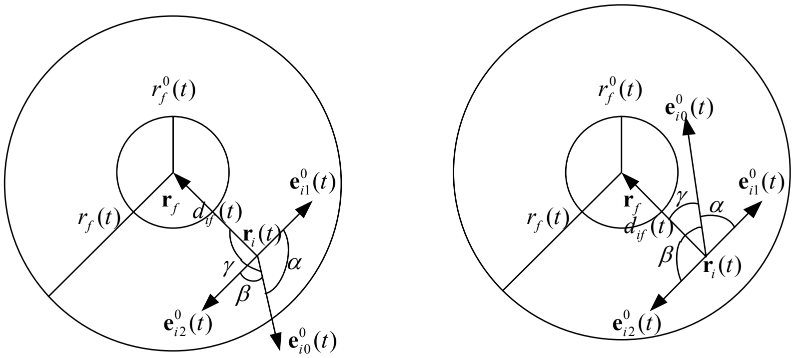
$$\mathbf{e}_{12}^1(\mathbf{r}_1,\mathbf{r}_2,r)=(e_{12}^1\cdot\sqrt{1-[r/d_{12}]^2}+e_{12}^2(t)\cdot r/d_{12},e_{12}^2\cdot\sqrt{1-[r/d_{12}]^2}-e_{12}^1(t)\cdot r/d_{12}) \tag{5}$$

$$\mathbf{e}_{12}^2(\mathbf{r}_1,\mathbf{r}_2,r)=(e_{12}^1\cdot\sqrt{1-[r/d_{12}]^2}-e_{12}^2(t)\cdot r/d_{12},e_{12}^2\cdot\sqrt{1-[r/d_{12}]^2}+e_{12}^1(t)\cdot r/d_{12}) \tag{6}$$

$$\langle\mathbf{e}_1,\mathbf{e}_2\rangle=\arccos(e_1^1\cdot e_2^1+e_1^2\cdot e_2^2) \tag{7}$$

$$\mathbf{e}_i^0(t)=\begin{cases}\mu\cdot\mathbf{e}_{i0}^0(t)+(1\text{-}\mu)\cdot\mathbf{e}^* & if\quad \alpha+\beta=\gamma\\ \mathbf{e}_{i0}^0(t) & \text{otherwise}\end{cases},\mathbf{e}^*=\min(\mathbf{e}_{i1}^0(t),\,\mathbf{e}_{i2}^0(t))=\begin{cases}\mathbf{e}_{i2}^0(t) & \alpha>\beta\\ \mathbf{e}_{i1}^0(t) & \alpha<\beta\end{cases} \tag{8}$$

Here, the final direction $\mathbf{e}_i^0(t)$ is a linear combination of $\mathbf{e}_{i0}^0(t)$ and $\mathbf{e}^*$, and μ is the coefficient of risk, which is discussed in Section 4.2.



a) Inside the region of the included angle   b) Outside the region of the included angle

Fig. 2 Illustration of the pedestrian inside the dangerous source

Fig. 2 illustrates the situations that pedestrian is inside the region of dangerous source $\left(d_{if}(t)<r_f(t)\right)$. In Fig. 2(a), pedestrian is walking out of the dangerous region $\left\langle\mathbf{e}_{i0}^0(t),r_f(t)\right\rangle>90°$, and he/she will choose the current desired direction. In Fig. 3(b), pedestrian is getting closer to the 'hard region' $\left\langle\mathbf{e}_{i0}^0(t),r_f(t)\right\rangle\le 90°$, and he/she should make an adjustment to the vertical directions to leave the area as soon as possible. The calculations of the two vertical directions and relevant included angles are listed as follows:

$$\mathbf{e}_{i1}^0(t)=\left(-e_{if}^2(t),e_{if}^1(t)\right) \tag{9}$$

$$\mathbf{e}_{i2}^0(t)=\left(e_{if}^2(t),-e_{if}^1(t)\right) \tag{10}$$

$$\mathbf{e}_i^0(t) = \begin{cases} \mu\mathbf{e}_{i0}^0(t) + (1-\mu)\mathbf{e}_{i2}^0(t) & \alpha > \beta \\ \mu\mathbf{e}_{i0}^0(t) + (1-\mu)\mathbf{e}_{i1}^0(t) & \alpha < \beta \end{cases} \tag{11}$$

3.2. Repulsive force

The motion of a pedestrian is influenced by other surrounding (neighbor) pedestrians. In particular, a pedestrian is willing to keep a certain distance from other pedestrians or avoid collisions with others. When someone gets closer to the pedestrian, he/she normally feels increasingly uncomfortable. When the pedestrian contacts with others, contact force dominates the movement. The repulsive force from other pedestrians can be formulated as follows:

$$\mathbf{f}_{ij} = \left\{ A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right] + kg\left(r_{ij} - d_{ij}\right)\right\} \cdot \mathbf{n}_{ij} + \kappa g\left(r_{ij} - d_{ij}\right)\Delta v_{ji}^t \cdot \mathbf{t}_{ij} \tag{12}$$

The formulation is based on the literature (Helbing, 2000). The first item represents the non-contact repulsive social force exerted by other pedestrian. A_i, B_i are parameters, A_i represents the repulsive social force at the moment of pedestrian j just contacting with pedestrian i. B_i represents the sustainable distance between two pedestrians. The second and third items represent the normal and tangential contact forces respectively. If pedestrians do not contact with each other, the force will equal zero; otherwise, the force will linearly increase with the contact distance.

$$g(x) = \begin{cases} x, & \text{if } x \geq 0 \\ 0, & \text{otherwise} \end{cases}, x = d_{ij} - r_{ij} \tag{13}$$

When calculating the tangential contact force, the projection of the speed difference Δv_{ji}^t is also included. Here, k, κ are the parameters. $\mathbf{n}_{ij}, \mathbf{t}_{ij}$ represent the directional vector of the normal direction and tangential direction. $\Delta v_{ji}^t = (\mathbf{v}_i - \mathbf{v}_j) \bullet \mathbf{t}_{ij}$. If the pedestrian becomes near to static obstacles or dangerous sources, he/she may also feel uncomfortable, nervous or even panic. Similarly, the repulsive effect of obstacle or dangerous source can be formulated by Eq. (12). Here, it is assumed that obstacles and dangerous sources are stationary objects and the velocities of them equal to zero, and $\Delta v_{ji}^t = -\mathbf{v}_j \bullet \mathbf{t}_{ij}$. The factors that are dangerous source and obstacles have different effect on pedestrian's movement behavior, so the parameters are set to different value. In this paper, $A_i^f = 3\times10^3\sqrt{r_f^0}$, $B_i^f = 0.5\times r_f^0$, $k^f = 2\times10^5 kgs^{-2}$, $\kappa = 2.4\times10^5 kgm^{-1}s^{-1}$.

4. Numerical results

The pedestrian's evacuation process consists of three parts that are recognizing the dangerous source, finding optimal desired direction, and moving along the direction to destination. In this section, the proposed model is used to simulate evacuation process in danger. The evacuation time depends on the width and location of alternative exits, the scale of pedestrians and the distribution of dangerous sources and obstacles; and therefore, estimating evacuation time is an important method to grasp the features of evacuation process. In simulations, all evacuations are implemented in a room with a single exit, and the size of room is 15m×15m. Pedestrians are randomly initialized in the room, and then evacuate from room as soon as possible. The influences of the factors on evacuation process will be detailed discussed.

4.1. The influence of width of exit and desired velocity

During the evacuation process of a number of pedestrians escaping from a room, pedestrians gather together and arching queuing may forms near the exits. The process can be regarded as a pedestrian flow passing through a bottleneck, and the width directly determines the capacity of exit. Simulations have been implemented to evaluate the egress time of an evacuation process in danger. In simulations, the width of exit varied from 1.0 m to 2 m, and the desired velocity varied from 0.5 m/s to 9 m/s. Fig. 3 illustrated the escape time with different desired velocities.

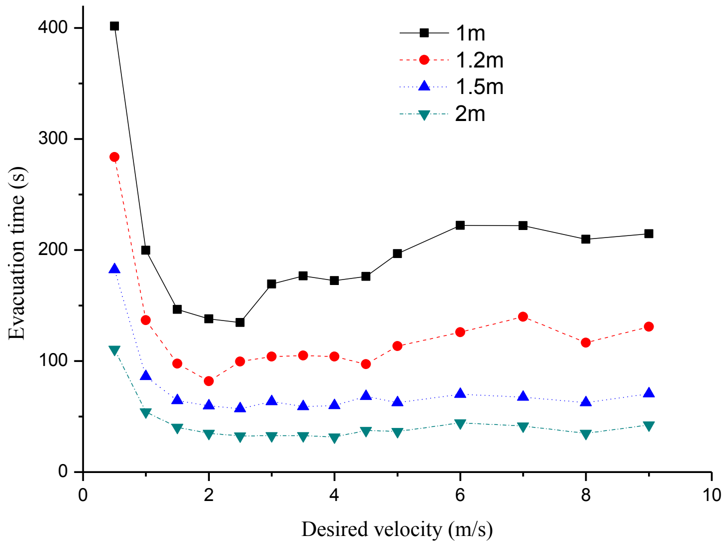


Fig. 3 Evacuation time with different desired velocities in different width

In evacuation, pedestrians want to walk fast, but actually they may spend more time on evacuation. The 'fast-is-slow' effect is an important self-organized phenomenon, and has been found in simulations (Helbing et al., 2000). From Fig. 3, the effect is obviously when the width is 1 m. If the desired velocity is smaller than 1 m/s, the evacuation time decreases with the increasing of desired velocity. If desired velocity is the range of 1 m/s to 2/5 m/s, the evacuation time decreases slowly. If desired velocity exceeds 2.5 m/s, evacuation time increases with desired velocity. In the case, the 'fast-is-slow' effect is obviously observed. When the width of exit increases to 1.2m, the effect can also be found, but is not significant. When the width exceeds 1.5 m, the effect can hardly be observed. It implies that the 'fast-is-slow' effect is more likely to occur in a narrow exit.

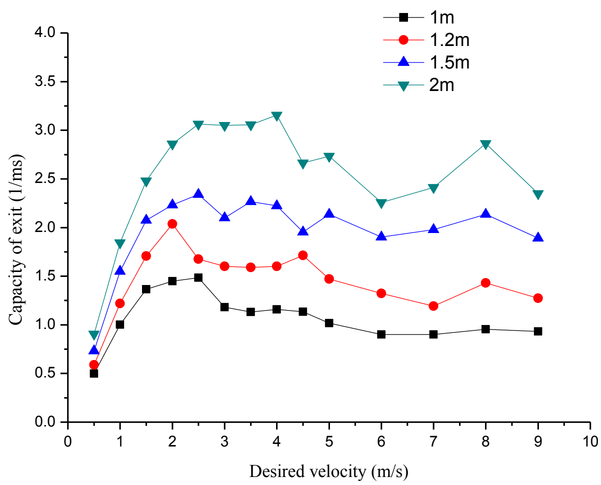


Fig. 4 Relationship between the desire velocity and capacity of exit

Fig. 4 illustrates the capacity under different desired velocities. The capacity that is defined as the maximal value for the flow (specific flow) influents the minimal evacuation time. Here, the specific flow denotes the capacity, and gives the flow per unit-width per second (Seyfried at al., 2009). In the case of a classical bottleneck, it is generally assumed that a jam will occur when the incoming flow exceeds the capacity of the bottleneck. From Fig. 4, it can be found that under a certain width of exit, the capacity firstly rapidly increases, then slowly declines, and finally stabilizes on a certain value. The result is in accord with the 'fast-is-slow' effect. In addition, the capacity increases with the width of exit, i.e., capacity is 1.3 (1/m.s) when width is 1 m; capacity is 1.7 (1/m.s) when width is 1.2 m; capacity is 2.2 (1/m.s) when width is 1.5 m; capacity is 2.9 (1/m.s) when width is 2 m.

Furthermore, the evacuation process with different numbers of people was investigated. The number of pedestrian varied from 20 to 200, and the desired velocity was set from 0.5 m/s to 5 m/s. Fig. 5 illustrates the evacuation time of different numbers of pedestrians escaping from the room. In our simulation, if the desired velocity was small, i.e., v = 0.5 m/s, pedestrians might block each other near exit and are not able to move. Therefore, some results were not shown in the figure. From Fig. 6, it could be found that the average evacuation time decreased with increasing of the numbers of people. It implied that a large number of people might lead to a large accumulative self-driven force and a faster velocity.

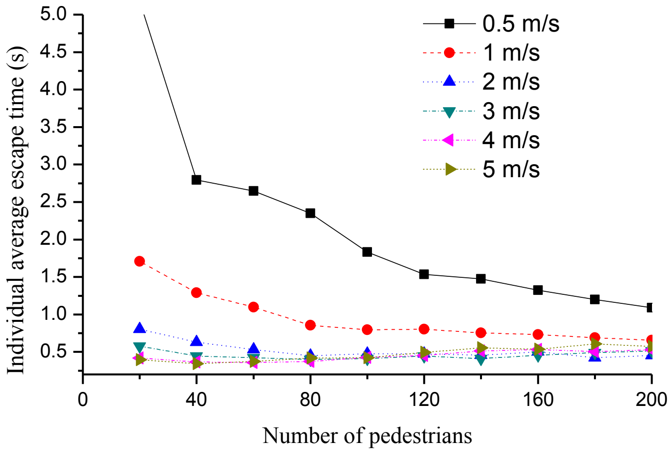


Fig. 5 Evacuation time with different numbers of people

4.2. Coefficient of risk

In our model, the coefficient of risk represents the probability of choosing the tangential direction to dangerous source. Pedestrians with high coefficient of risk are not fear of dangerous source and prefer to walk along the shortest path. The influence of risk coefficient on choice behavior is investigated according to simulations. In simulations, 150 pedestrians were randomly initialized in a room with a single exit; the size of the room was 15 m × 15 m, and the exit was 1.2 m in width. The desired velocity of each pedestrian was set to 3 m/s, the position of dangerous source was (6 m, 4.5 m), the initial radius was 3m, and the spreading parameter was 0.012 (s^{-1}). In simulations, the risk coefficient varied from 0 to 1 with an interval of 0.1.

The relationship between number of evacuated pedestrians and coefficient of risk was shown in Fig. 6. If dangerous source was far away from exit, the risk coefficient would have little effect on evacuation time, and the influence reflected on the trajectories of pedestrian; conversely, if dangerous source was near exit, the coefficient would have a significant influence on evacuation time and trajectories of movement. With increasing of radius of dangerous source, the repulsive force from the dangerous source grew rapidly. The self-driven force showed a little change, and the total force was mainly composed of repulsive force. If pedestrians were not willing to make a risk, they would be trapped in the room with the spreading of dangerous source. It implied that a small risk coefficient might also lead to serious consequences.

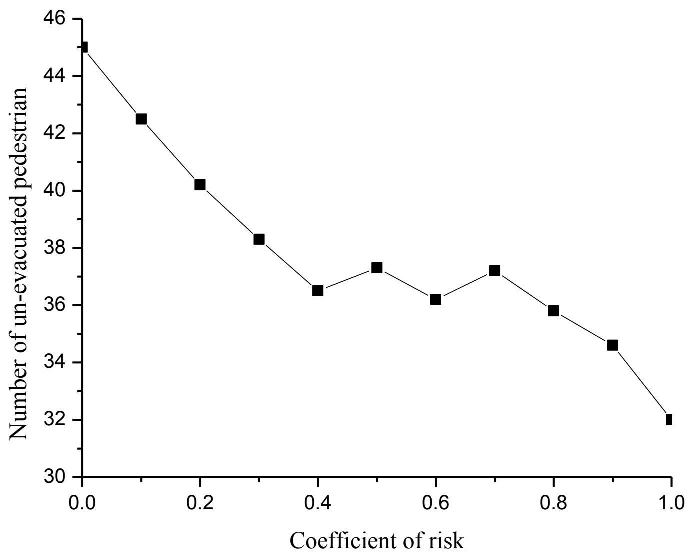


Fig. 6 Relationship between evacuated pedestrians and coefficient of risk

The relationship between evacuation time and risk coefficient was illustrated in Fig. 7. It could be found that with the increasing of risk coefficient, the number of un-evacuated pedestrians and average evacuation time showed a tendency of decrease. It was because pedestrians with larger risk coefficient might pass through the dangerous region as soon as possible. They could even move into the region and find the shortest path. In the situation, the self-driven force sometimes directly pointed to the exit, and the required evacuation time of each pedestrian decreased. In addition, a shorter walking distance might reduce the evacuation time.

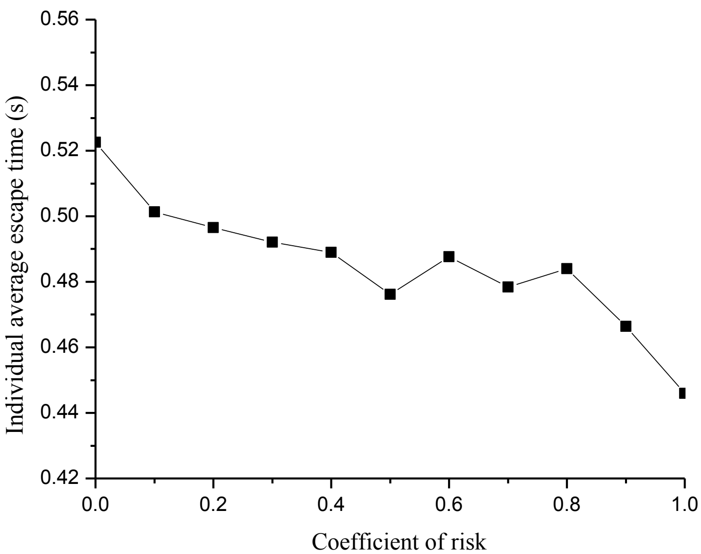


Fig 7 Relationship between the evacuation time and coefficient of risk

5. Conclusion

In this paper, the behavior of evacuation process in danger is detailed analyzed and quantitatively formulated. A modified social force model is proposed to describe pedestrian's movement behavior. In the model, the influence of dangerous source is taken into consideration, and the self-driven force and repulsive force of original social force model are modified. The affect region of dangerous source is assumed to be a circle, and the most possible detouring directions are calculated according to geometry theory. In addition, the spreading dynamics of dangerous sources and coefficient of risk are included. According to simulations, the influences of all mentioned factors are discussed. The width of exit has a significant influence on the evacuation time. 'Fast-is-slow' effect is observed in our simulation, and the phenomenon is more like to occur near a narrow exit. With the increase of exit width, the capacity of exit linearly increases. During evacuation, a larger coefficient of risk and shorter walking distance might reduce the evacuation time, and a small risk coefficient might also lead to serious consequences. The further research will be: (1) to obtain the empirical or observational data, (2) to make a validation of the model according to the data, (3) to calibrate the parameters in the model, (4) to combine the model with present software to precisely describe the movement behavior.

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